

Muons, Inc., IIT, Jlab, Fermilab: SBIR/STTR Muon Projects

Rolland Johnson, October 15, 2004

- HP HG GH2 RF
 - Ph II, w IIT, DK
- 6D HCC **NEW!**
 - Ph II, w Jlab, YD
- Pulse Compression
 - Awarded, not funded
- H2 Cryostat **NEW Award!**
 - w FNAL, VY
- MANX **NEW Award!**
 - w FNAL, VY
- PIC **NEW Award!**
 - w Jlab, YD
- New Proposals in Progress

Thanks to Excellent Collaborators

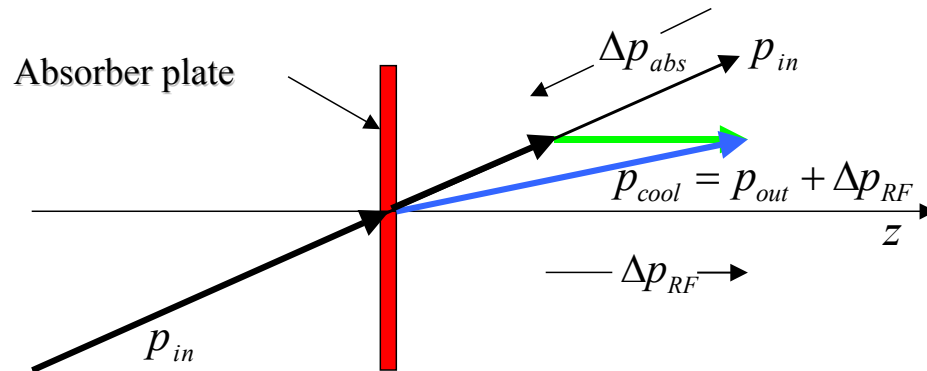
- IIT; Dan Kaplan, Tom Roberts, Katsuya Yonehara
- JLab; Slava Derbenev, Alex Bogacz, Kevin Beard
- Fermilab; Victor Yarba, Chuck Ankenbrandt, Emanuela Barzi, Timer Khabiboulline, Al Moretti, Milorad Popovic, Gennady Romanov
- Muons, Inc.; Mohammad Alsharo'a, Pierrick Hanlet, Bob Hartline, Moyses Kuchnir, Kevin Paul, Tom Roberts

Project 1: HP HV RF Cavities

Ph II, Dan Kaplan, IIT

- Dense GH_2 suppresses high-voltage breakdown
 - Small MFP inhibits avalanches (**Paschen's Law**)
- Gas acts as an energy absorber
 - Needed for ionization cooling
- Only works for muons
 - No strong interaction scattering like protons
 - More massive than electrons so no showers

Ionization Cooling Principle



2003 STTR Phase II Project

- To develop RF cavities, pressurized with dense hydrogen or helium gas, that are suitable for use in muon cooling and accelerator applications.
- Measurements of RF parameters (e.g. breakdown voltage, dark current, quality factor) for different temperatures and pressures in magnetic and radiation fields will be made in RF cavities to optimize the design of prototypes for ionization cooling demonstration experiments

High-Pressure RF Test Cell w Moly Electrodes at Lab G

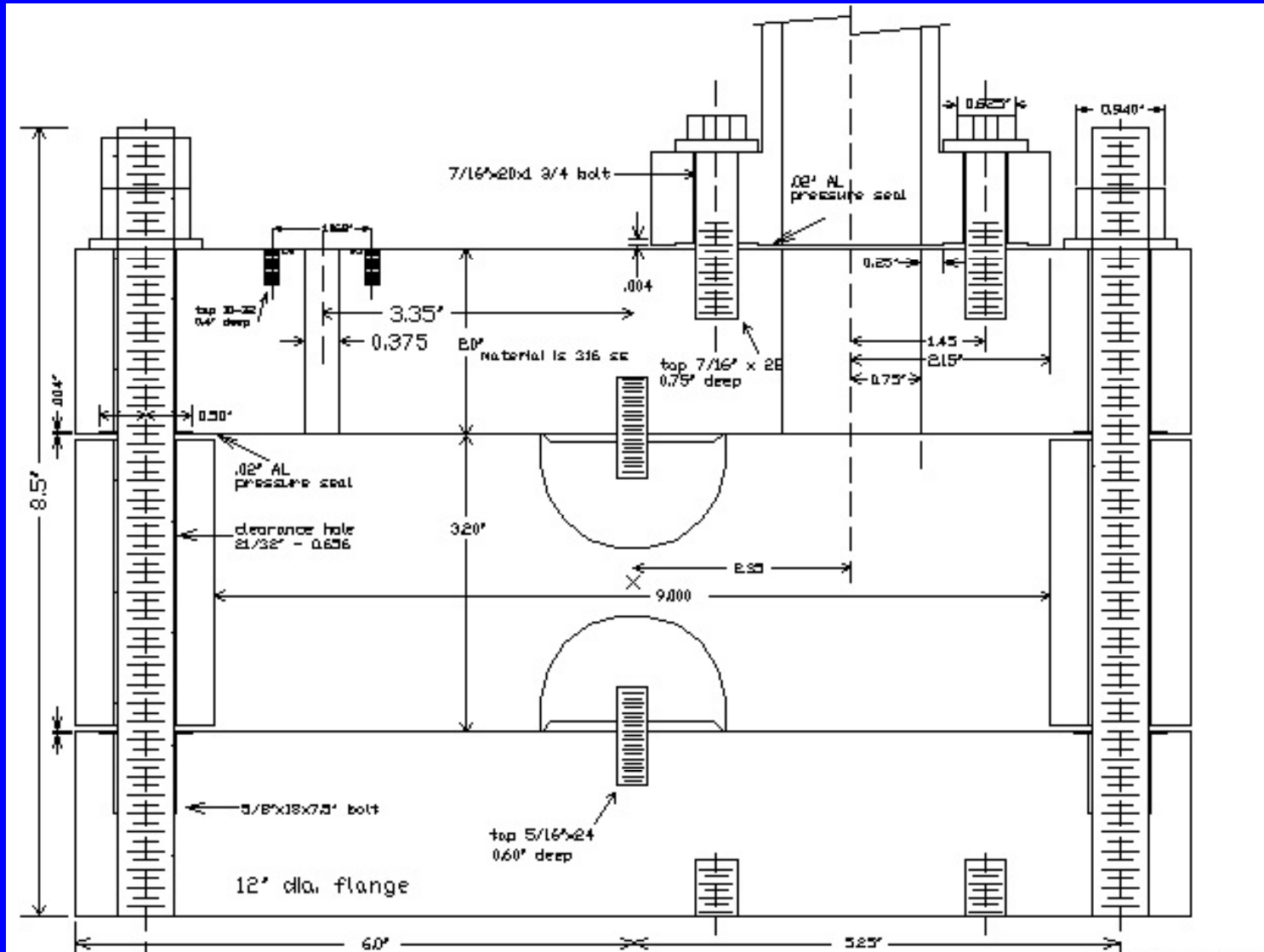
R. E. Hartline, R. P. Johnson, M. Kuchnir
Muons, Inc.

C. M. Ankenbrandt, A. Moretti, M. Popovic
Fermilab

D. M. Kaplan, K. Yonehara
Illinois Institute of Technology

See MuCool Note 285 for paper

Mark II 805 MHz RF test cell



New TC; 2000PSI @ 77K



10/15/04

Friday Meeting

8

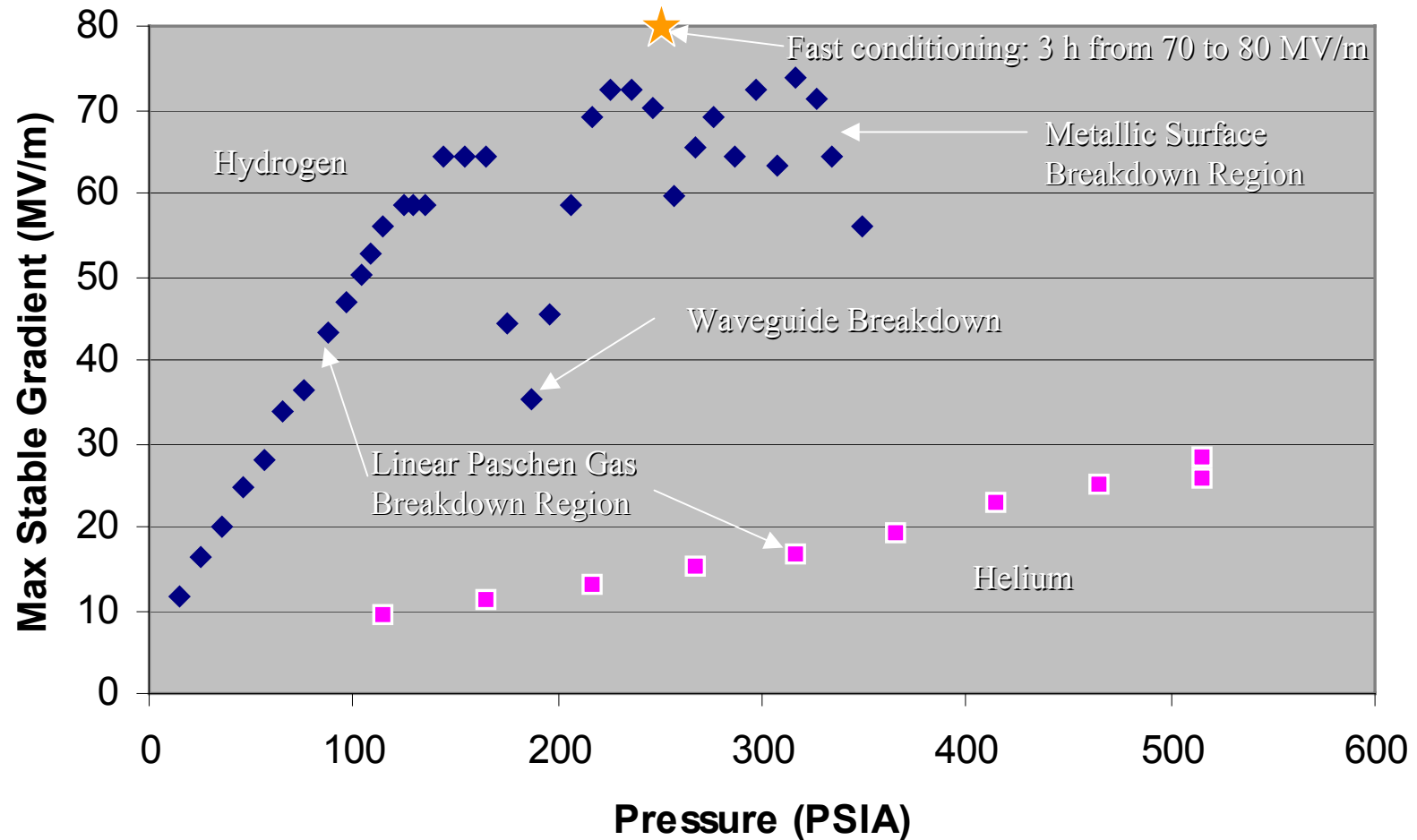


10/15/04

Friday Meeting

9

H2 vs He RF breakdown at 77K, 800MHz



Hopes for HP GH2 RF

- Higher gradients than with vacuum
- Less dependence on metallic surfaces
 - Dark currents, x-rays diminished
 - Very short conditioning times already seen
- Easier path to closed-cell RF design
 - Hydrogen cooling of Be windows
- Use for 6D cooling and acceleration
 - Homogeneous absorber concept
 - Implies HF for muon acceleration (1.6 GHz)

Present Activities for HP RF Phase II project

- Moving from Lab G to MTA
- Studying RF breakdown with cu, mo, cr, be electrodes 50:85:112:194 (Perry Wilson)
- Planning Test Cell for Operation in the LBL 5 T solenoid at 1600 PSI and 77K
- Working on MTA Beam Line
 - Want radiation test of GH2 RF in 2005

2004 Phase II, w JLab, Derbenev GH2 Emittance Exchange

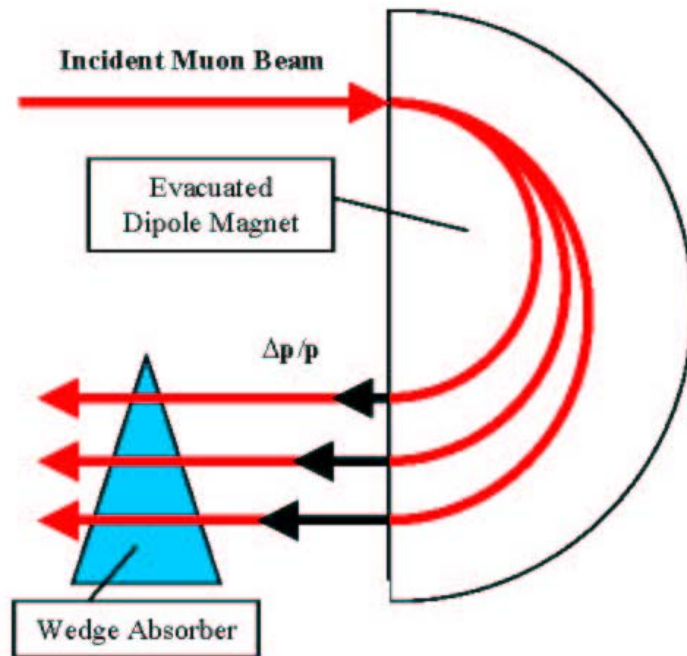


Figure 1. Use of a Wedge Absorber for Emittance Exchange

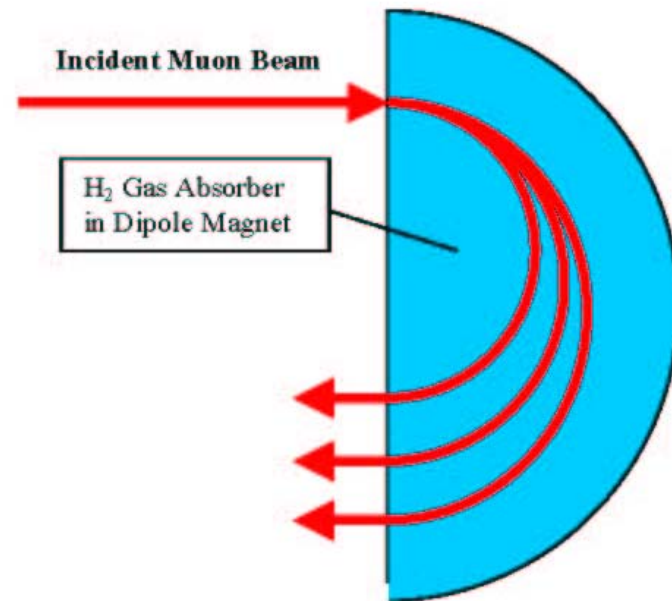


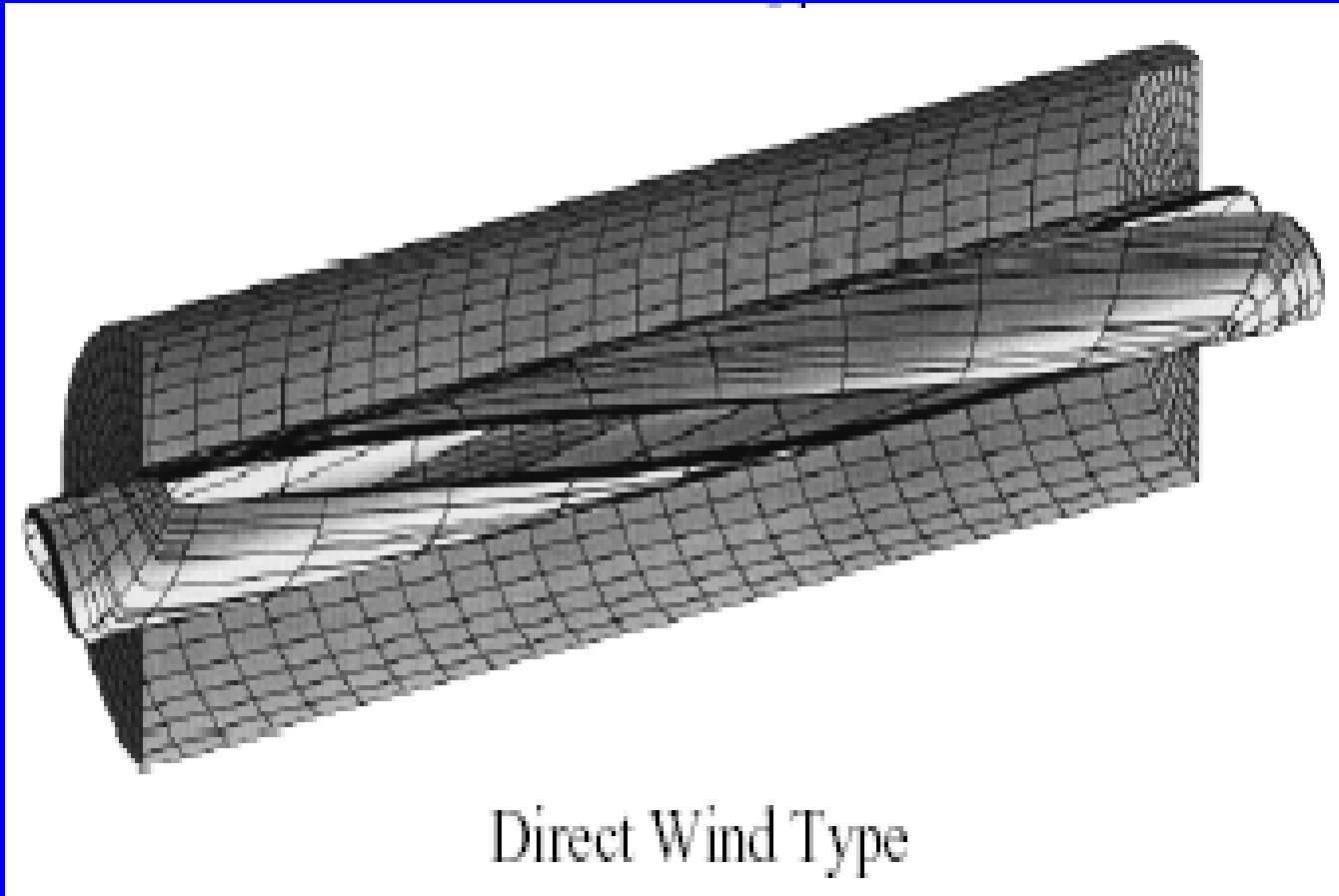
Figure 2. Use of Continuous Gaseous Absorber for Emittance Exchange

This concept of emittance exchange with a homogeneous absorber first appeared in our 2003 SBIR proposal!

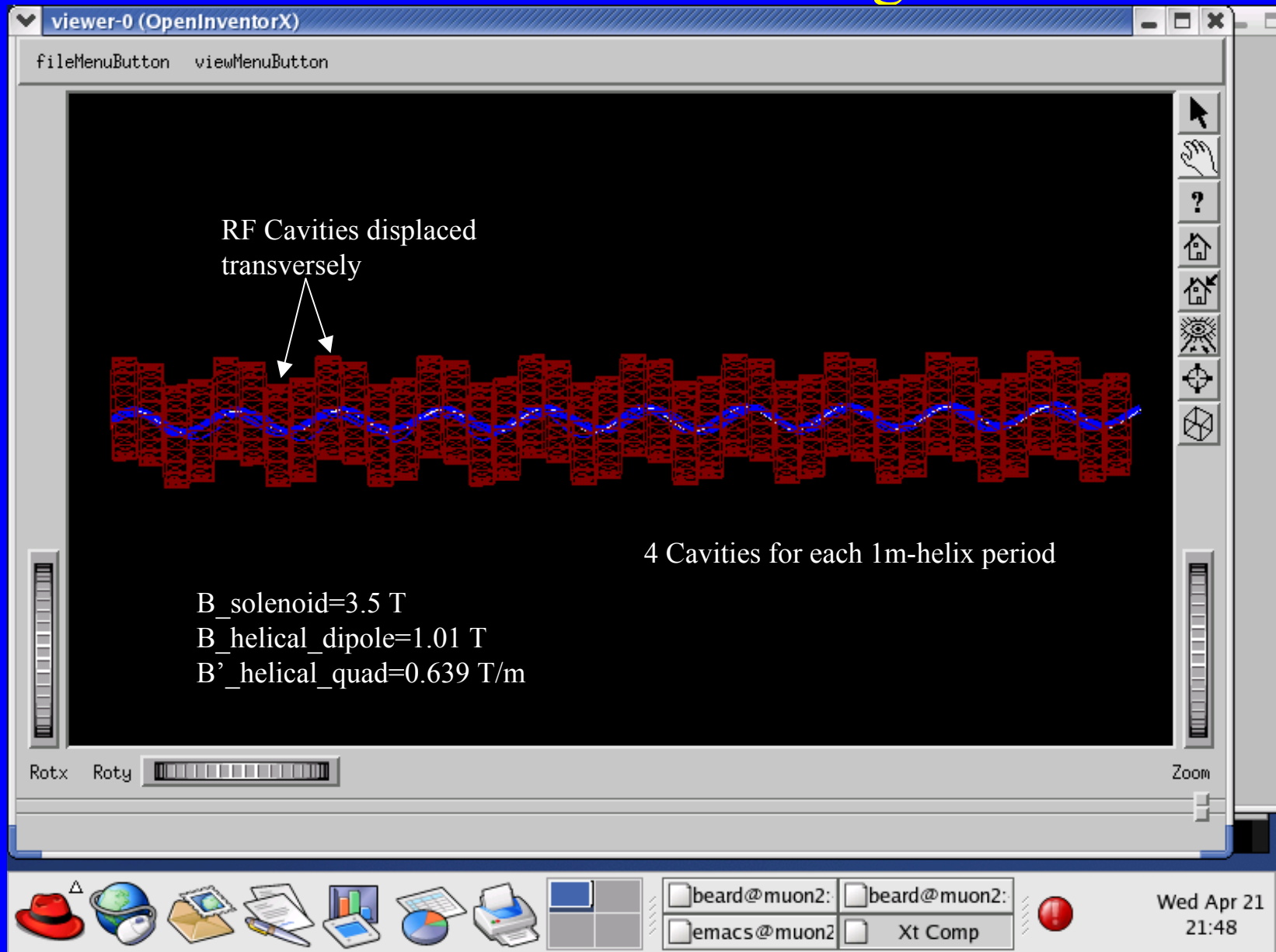
6D Cooling with GH2

- Helical cooling channel (HCC)
 - Solenoidal plus transverse helical dipole and quadrupole fields
 - z-independent Hamiltonian
- Avoids ring problems
 - Injection and Extraction
 - Multi-pass Beam loading or Absorber heating
 - Fixed channel parameters as beam cools

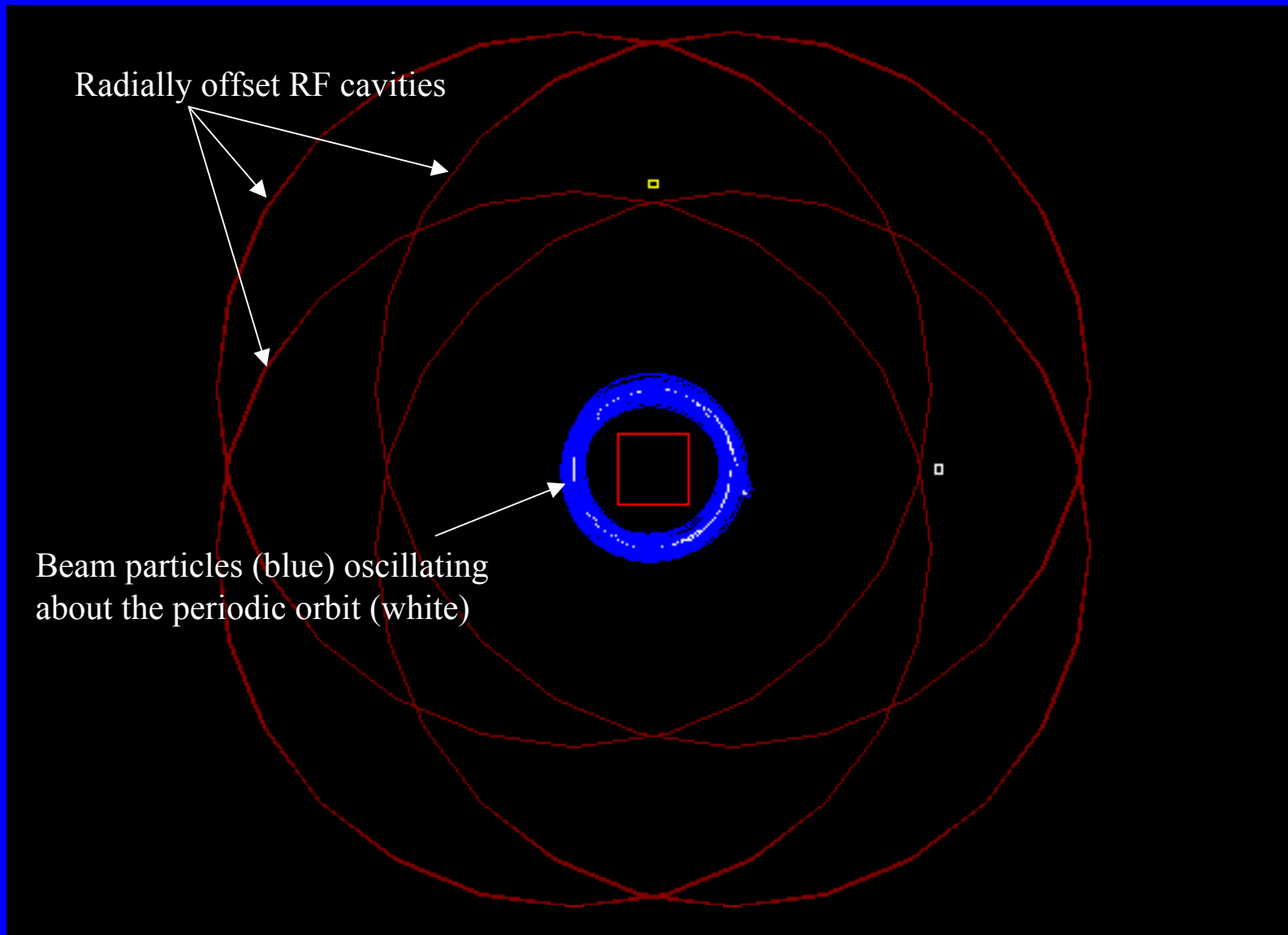
Helical Dipole Magnet (c.f. Erich Willen at BNL)



G4BL 10 m helical cooling channel

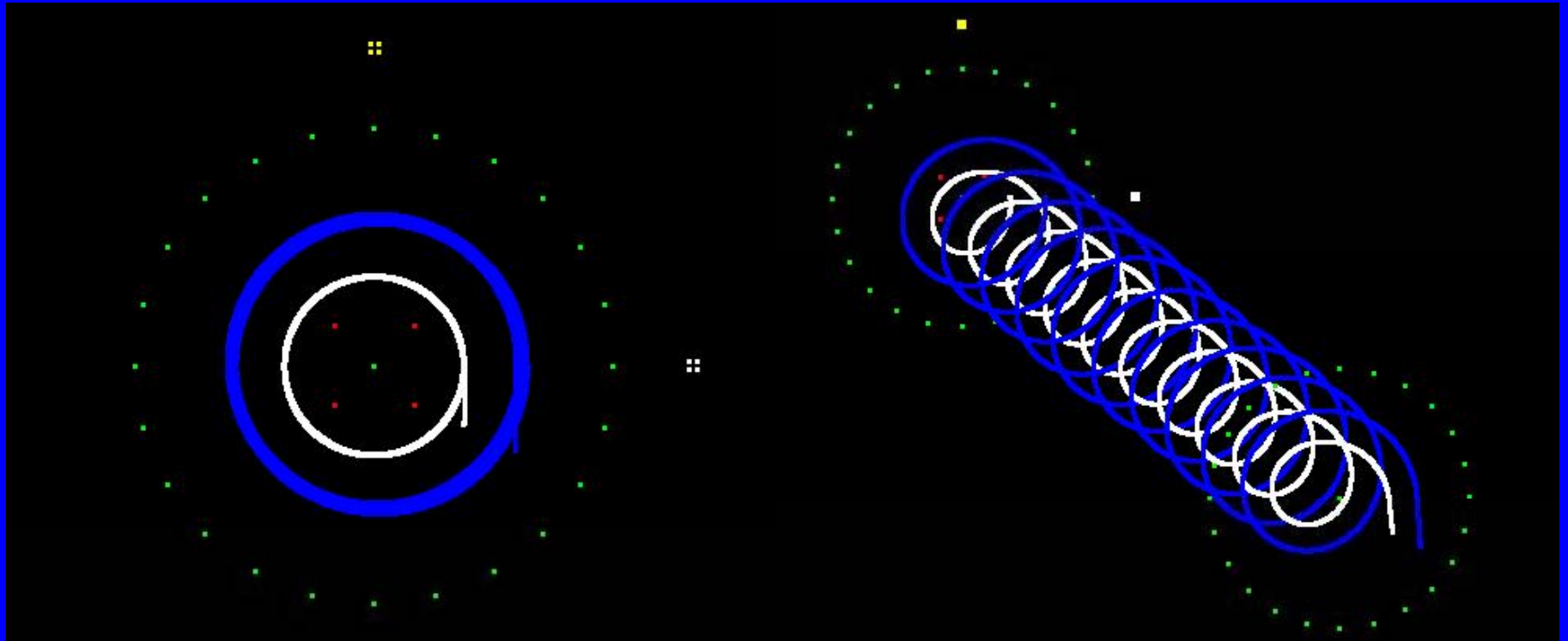


G4BL End view of 200MeV HCC



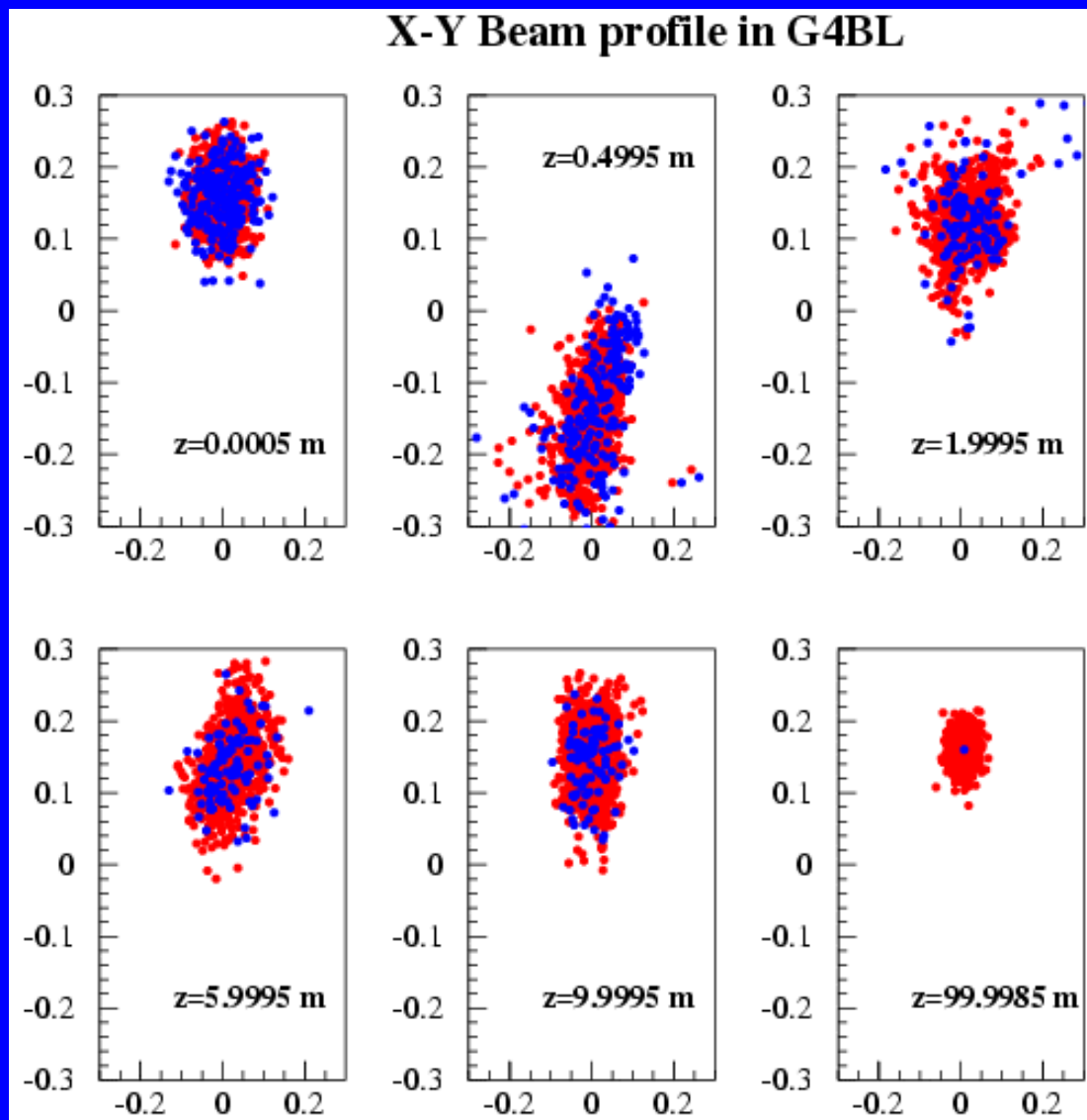
G4BL HCC Dispersion Measurement:

$$r_{250} = (1+0.25D) r_{200}, D=2.93$$



200MeV/c (white), 250 MeV/c (blue) periodic orbits

Yonehara Simulation results

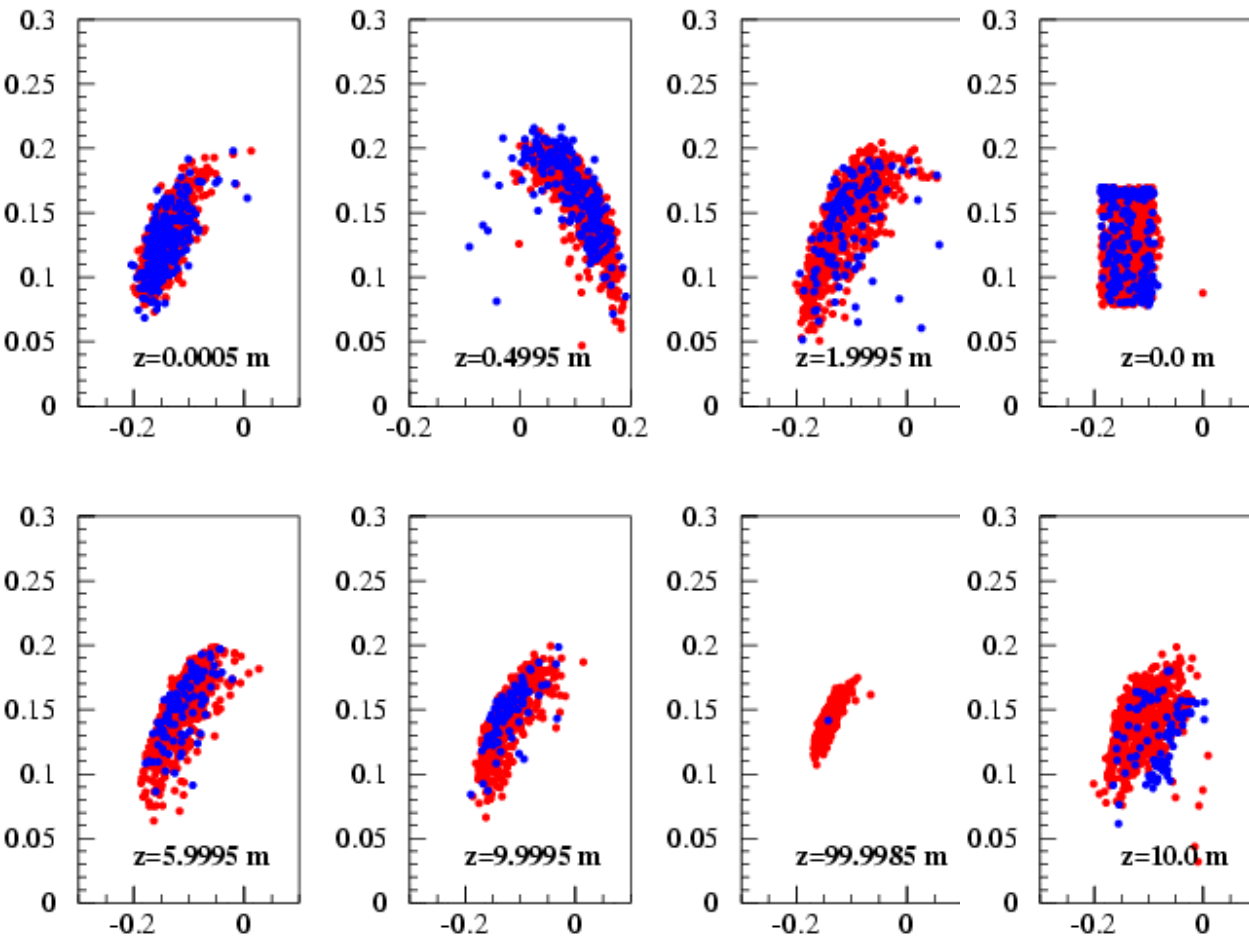


1,000 test particle

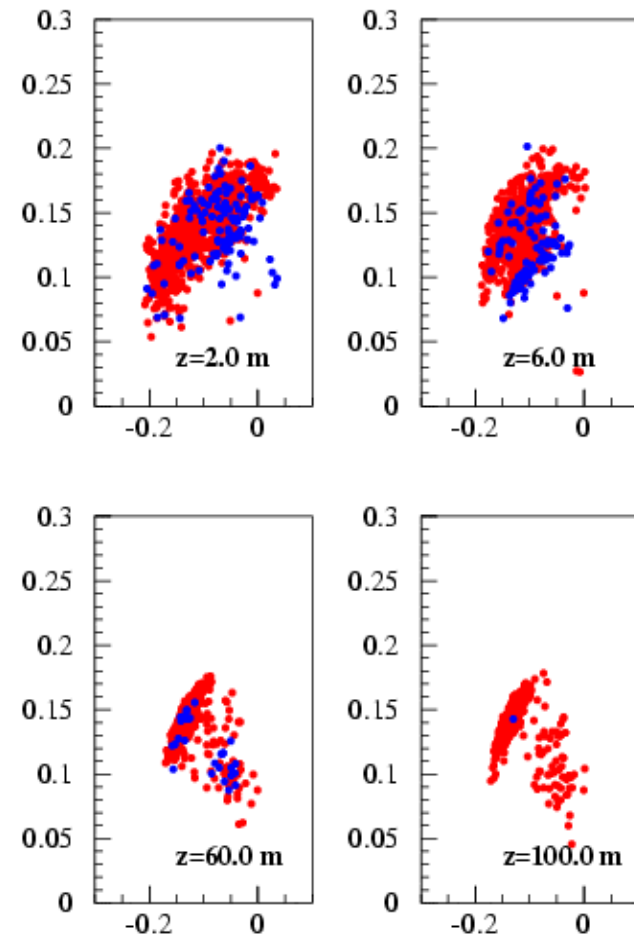
Blue: Bad particle
Red: Good particle

Simulation results (pX-pZ)

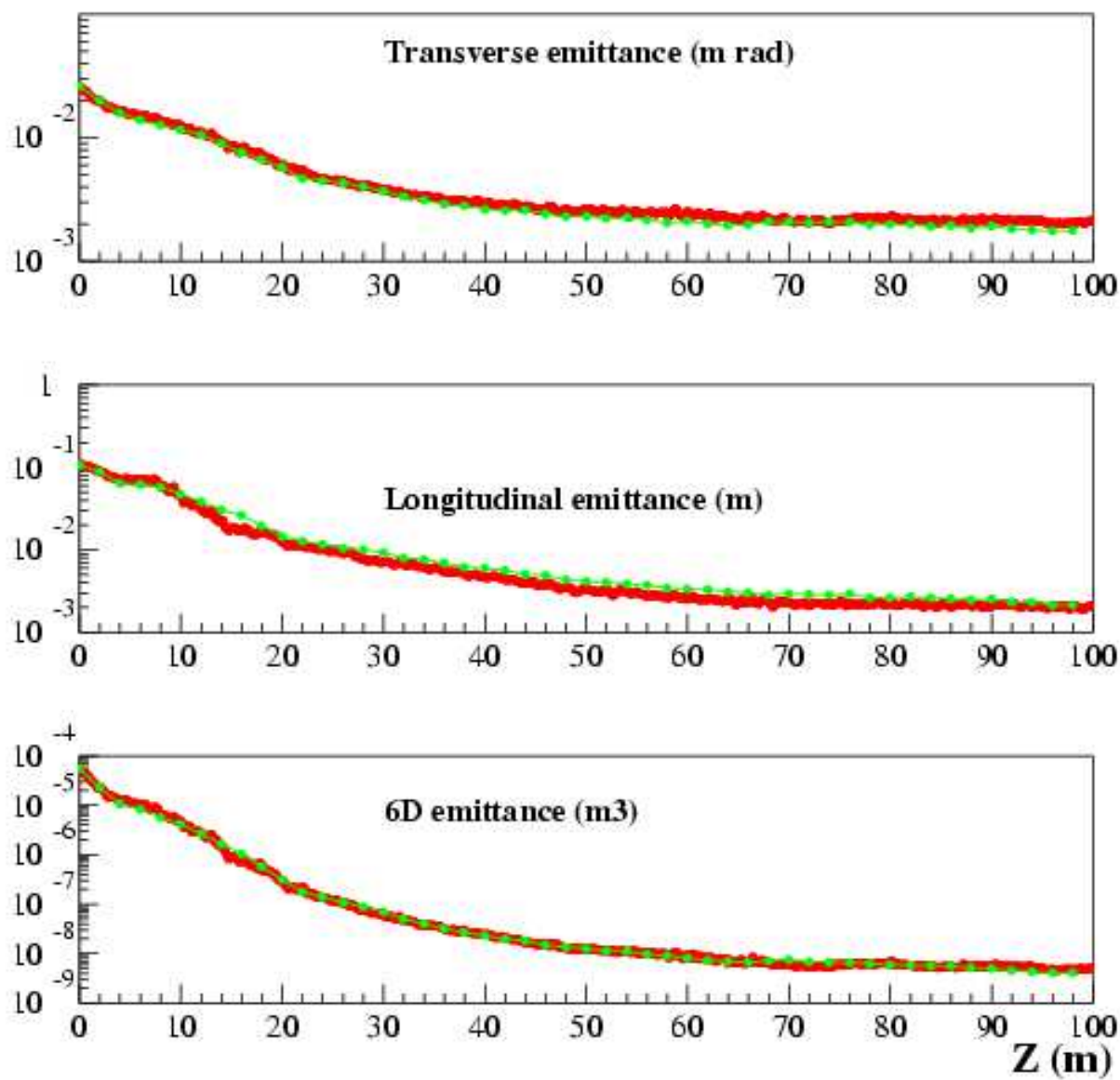
pX-pZ Beam profile in G4BL



pX-pZ Beam profile in ICOOL



Evolution of Beam emittance



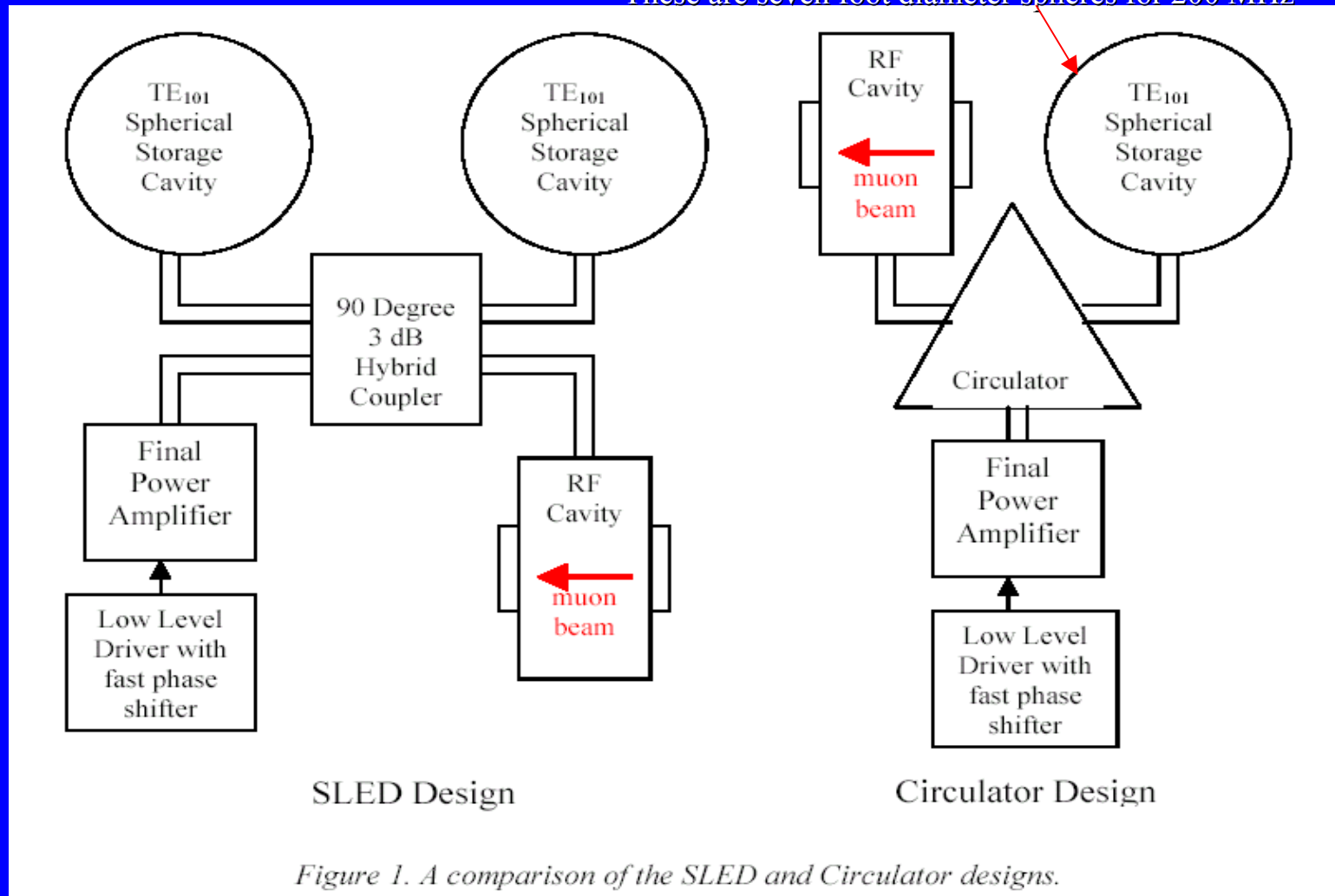
Status of 6D cooling project

- Interesting Ph I analytic, simulation results
 - PRSTAB paper, MuCool Note 248 is preprint
 - ICOOL and GEANT4 HCC simulations under study; cooling and RF behavior under study
 - Precooling-without-RF study of HCC started
- Phase II just starting

Project 3 Cryogenic Pulse Compressors

Ph I, Dave Finley, Fermilab

These are seven foot diameter spheres for 200 MHz



Status of Cryogenic Pulse Compressor Project

- Principles developed for >50 MV/m @200MHz
 - Two compression schemes to get power compression by a factor of 7, or voltage by $\text{SQRT}(7)=2.65$
 - Cold RF increases voltage by (resistivity ratio) $^{1/4}=1.68$
 - Voltage thus increased by $(4.45 * 15) = 66.7$ MV/m

New 2004 Project!!

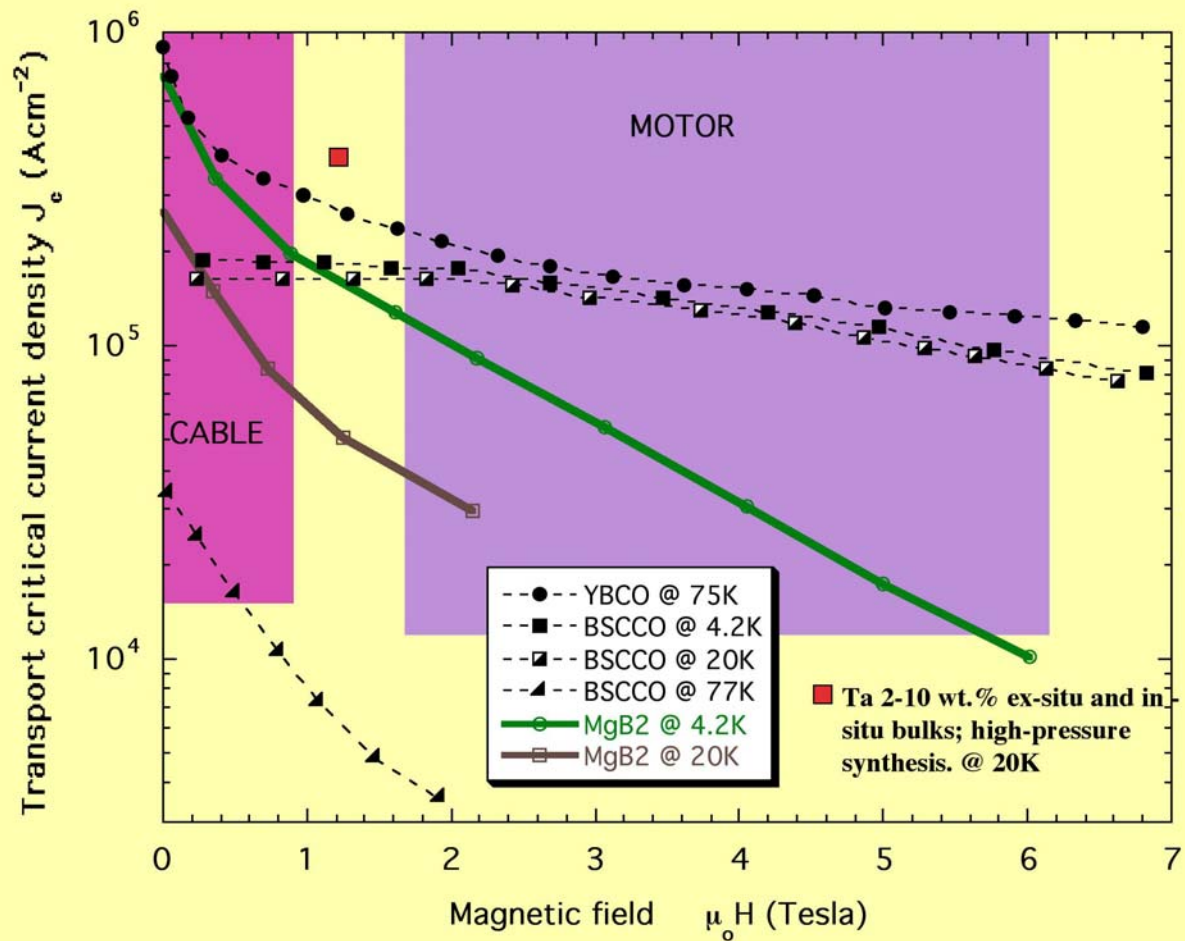
Hydrogen Cryostat

w Victor Yarba, Fermilab

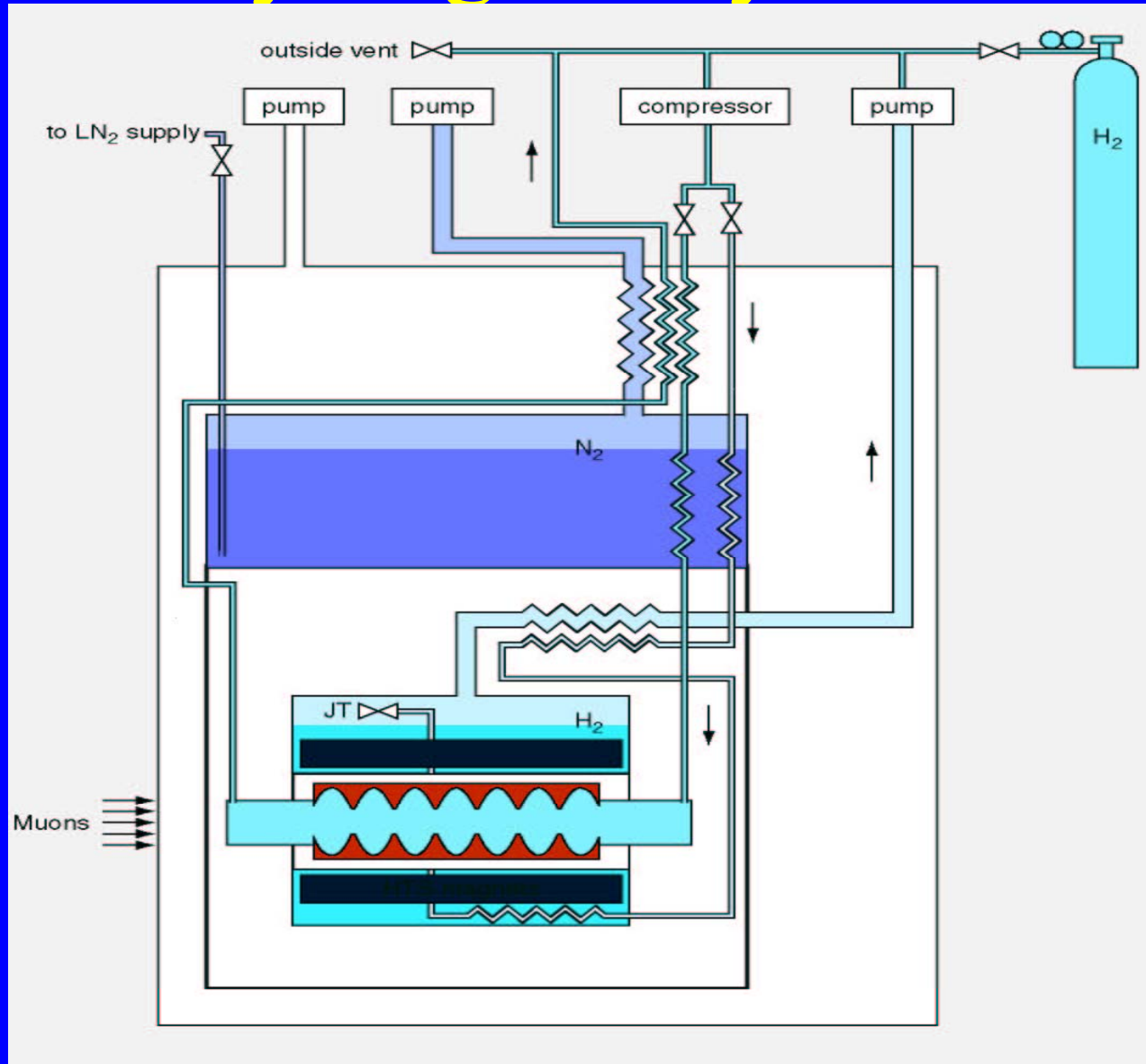
- simultaneously refrigerate
 - 1) HTS magnet coils
 - 2) cold copper RF cavities
 - 3) hydrogen gas heated by the muon beam
- extend use of hydrogen to that of refrigerant
 - besides breakdown suppressant and energy absorber
 - large amount of hydrogen for IC anyway
- relevance for hydrogen economy?
- Dr. Moyses Kuchnir

HTSC I, B, T

APPLICATIONS



Hydrogen Cryostat



New 2004 Project!!

MANX

Muon Collider And Neutrino Factory experiment

Ph I, w Victor Yarba, Fermilab

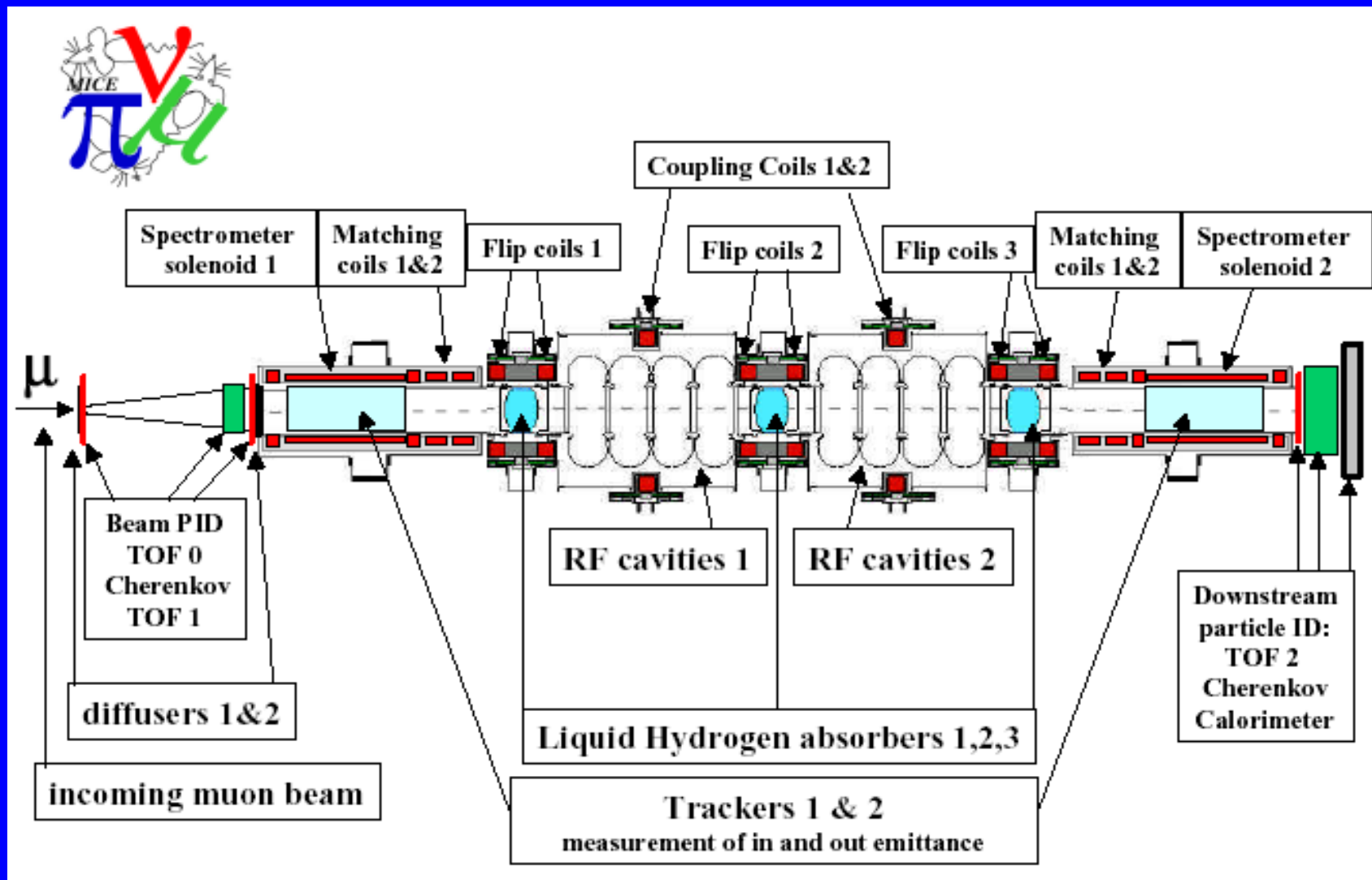


- Hi-Pressure GH2
- Continuous Absorber
- Continuous low- β
 - Single-flip Solenoids
- Internal Scifi detectors
 - Minimal scattering
- MANX follows MICE
 - Engineering proof

MANX comparison to MICE

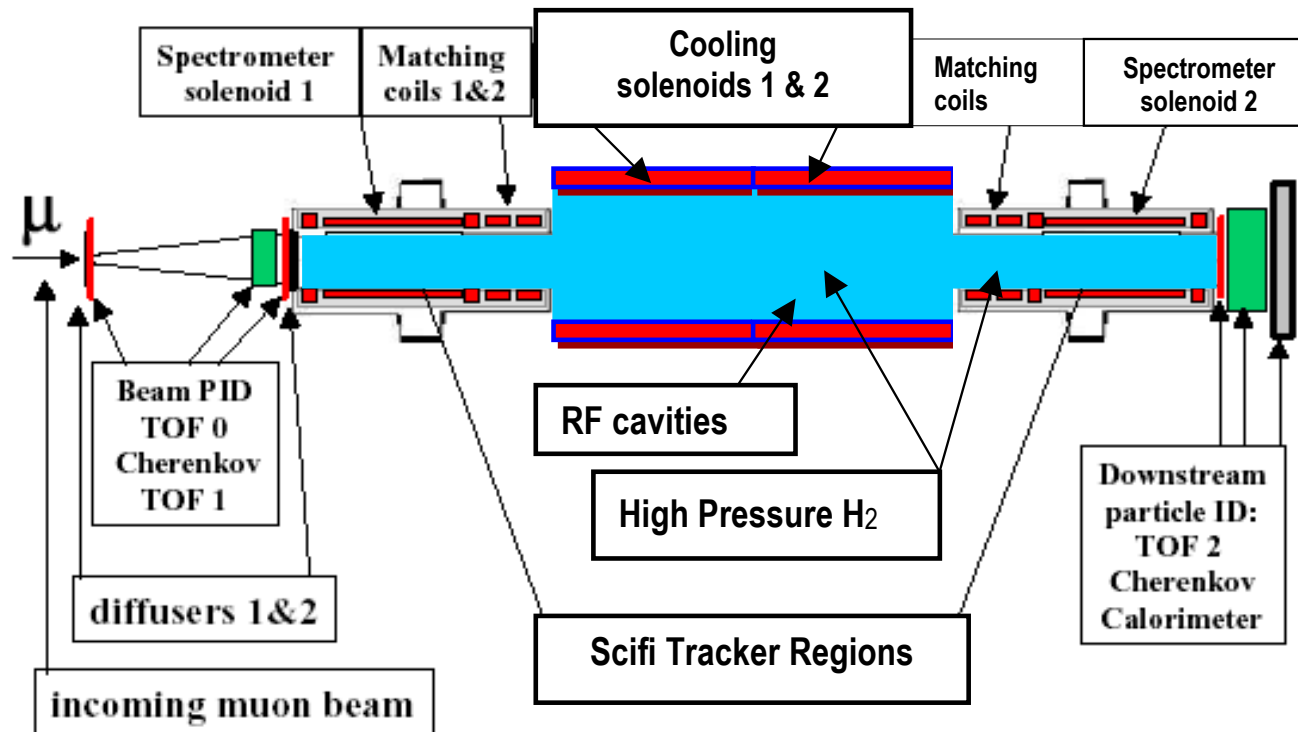
- Conventional LH2 cooling channel
 - Liquid hydrogen absorbers between RF cavities
 - Placed at low β locations, where solenoidal fields change direction
- Proposed GH2 cooling channel
 - Continuous dense hydrogen absorber fills RF cavities
 - Low β is continuous along channel

MICE



MANX is GH2 version of MICE

MANX



New 2004 Project!!

Phase Ionization Cooling (PIC)

Slava Derbenev, Jlab

- Derbenev: 6D cooling allows new IC technique
- PIC Idea:
 - Excite parametric resonance (in linac or ring)
 - Like vertical rigid pendulum or $1/2$ -integer extraction
 - Use $xx' = \text{const}$ to reduce x , increase x'
 - Use IC to reduce x'
- 1 to 2 orders smaller emittance than usual IC
 - Fewer muons needed for high luminosity MC
 - Easier proton driver and production target
 - Fewer detector backgrounds from decay electrons
 - Less neutrino-induced radiation

Hyperbolic phase space motion

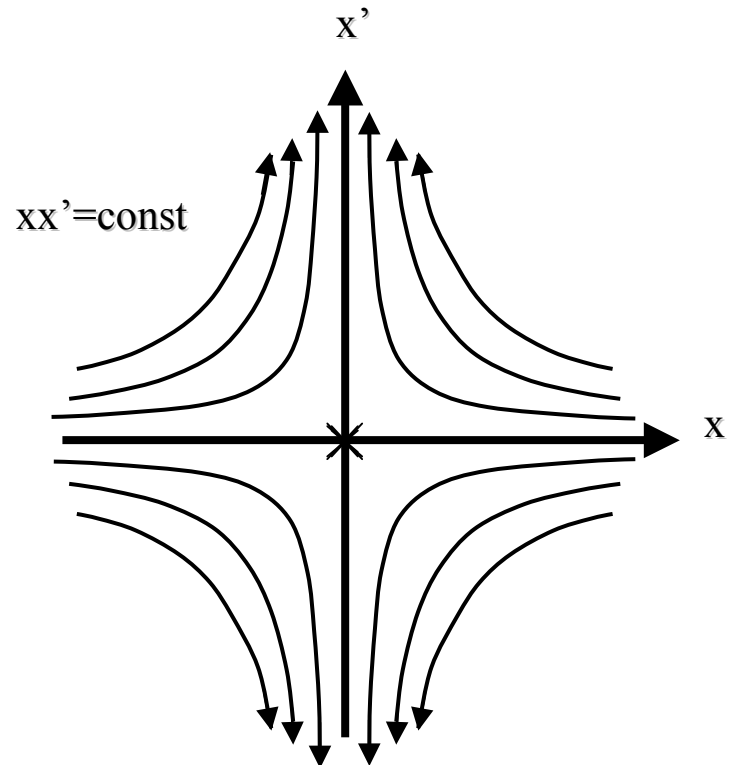
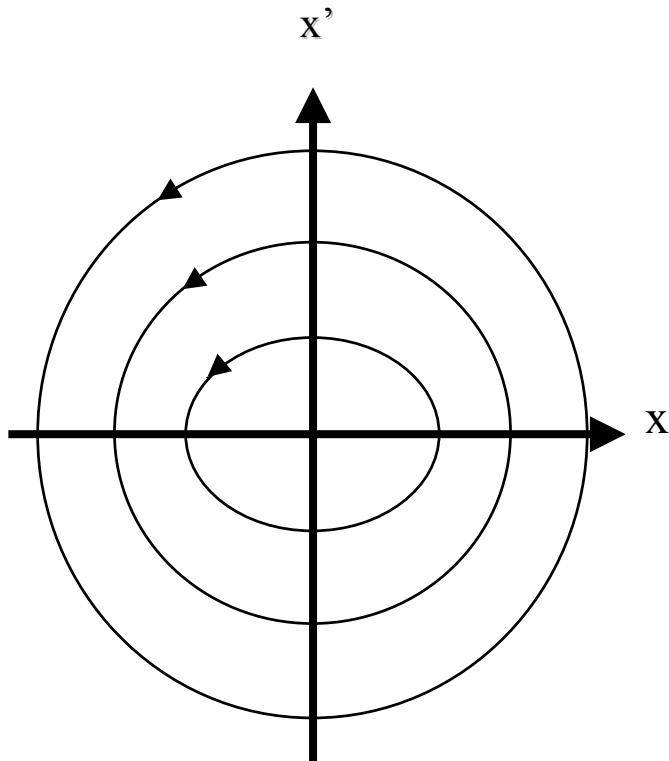
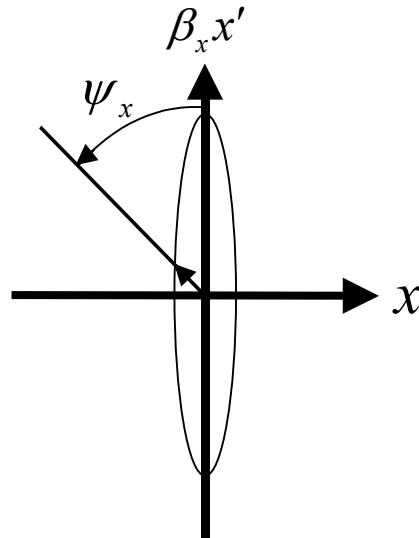
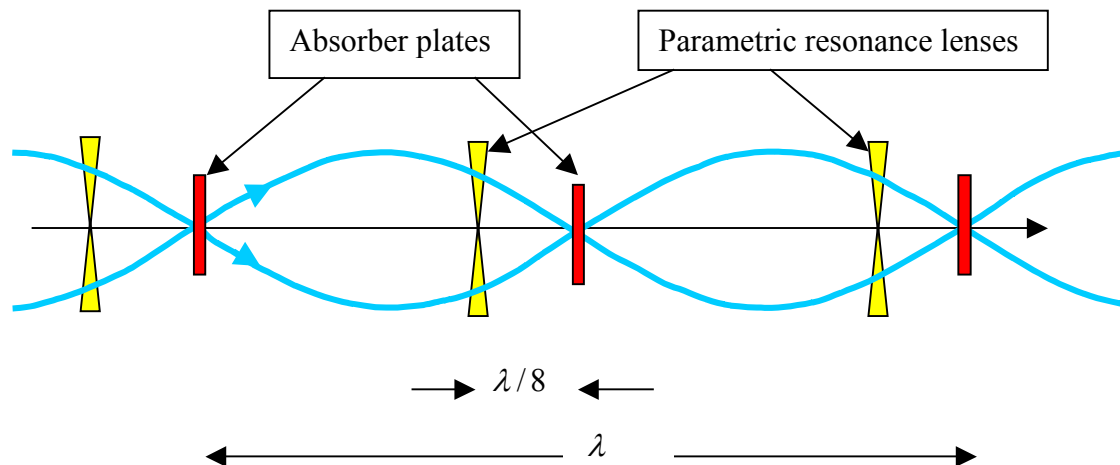


Fig. 3 Phase space compression. The spread in x diminishes due to the parametric resonance motion while the spread in x' diminishes due to ionization cooling. The area of the occupied phase space ellipse is reduced as the particles are restricted to a narrow range of phase angle, ψ .



PIC concept first appears in our 2004 SBIR proposal! First paper EPAC2004, YD,RJ.

Transverse PIC schematic



Conceptual diagram of a beam cooling channel in which hyperbolic trajectories are generated in transverse phase space by perturbing the beam at the betatron frequency, a parameter of the beam oscillatory behavior. Neither the focusing magnets that generate the betatron oscillations nor the RF cavities that replace the energy lost in the absorbers are shown in the diagram.

The longitudinal scheme is more complex.

GOAL: Higgs Factory at Fermilab using new muon beam cooling ideas

- μ cooling technique
 - Initial Precooling implies
 - 6D cooling in helix
 - Needs HPRF
 - Parametric resonance
 - Ionization Cooling
 - Reverse emittance exchange (next SBIR proposal)
- ϵ_N transverse (mm-mr)
 - 10^4
 - 10^2 (usual IC limit)
 - 6D cooling is 10^6
 - 10
 - 1

Smaller ε_T means fewer μ

$$\mathcal{L} \approx \frac{N_{\mu^+} N_{\mu^-}}{\beta_{\perp} \varepsilon_N}$$

Factor of 100 lower emittance means factor 10 fewer muons needed.

Then, proton driver needs 400kW, not 4MW on target (new Linac * MI)

Neutrino radiation problem reduced.

Detector backgrounds reduced.

Take advantage of $(m_{\mu}/m_e)^2=40,000$ s-channel Higgs production cross-section.

Needs Booster sized ring.

After the Higgs factory, the next step is an energy frontier muon collider using Tesla cavities (perhaps with recirculation) to feed a 2 (or more) TeV ring.

New Proposals Due 12/13/04

- Muons, Inc. workshop 10/4-5/04 had 14 ideas for new Phase I proposals.
- Four presently being developed
 - HCC Magnets
 - RevEmEx
 - G4BL
 - Muon Precooling, bunching
- More as time allows

Summary

- Take advantage of unique properties of muons
 - Pressurized RF Cavities
 - 6D Cooling with homogeneous absorber
 - May make Muon Collider possible
 - Less expensive acceleration for Neutrino Factory
- Once 6D cooling is achieved, use other tricks
 - Parametric Resonance Ionization Cooling
 - Maybe Reverse Emittance Exchange
- Is a Higgs Factory an intermediate step to an Energy Frontier Muon Collider?